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## Tribological Properties of Coal Slurries

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**NASA**

# TRIBOLOGICAL PROPERTIES OF COAL SLURRIES

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## SUMMARY

E-3634

A pin-on-disk tribometer was used to study the tribological properties of methyl alcohol-coal slurries. Friction coefficients, steel pin wear rates and wear surface morphological studies were conducted on AISI 440C HT and M-50 bearing steels which were slid dry and in solutions of methyl alcohol, methyl alcohol-fine coal particles, and methyl alcohol-fine coal particles-flocking additive. The flocking additive was an oil which was derived from coal and originally was intended to be added to the coal slurry to improve the sedimentation and rheology properties. The results of this study indicated that the addition of the flocking additive to the coal slurry markedly improved the tribological properties, especially wear. In addition, the type of steel was found to be very important in determining the type of wear that took place. Cracks and pits were found on the M-50 steel pin wear surfaces that slid in the coal slurries while 440C HT steel pins showed none.

## INTRODUCTION

The need for alternate fuels has led to renewed efforts to utilize coal in a propitious manner. There has been some discussion in the aerospace industry that coal slurries might be a viable fuel for future aircraft turbine engines. Most likely this will not take place in the near future, but coal slurries might be amenable to certain terrestrial applications right now. The usual approach for utilizing coal in a terrestrial application has been to convert existing oil-fired facilities to coal-fired ones. However, this conversion is quite expensive. One alternative might be to make the coal into a fine powder and then to disperse it in either water or methyl alcohol. Either of these hybrid fuels could then be fired in a conventional oil-burning facility with only minimal conversions having to be made. In either of these two applications, wear of metallic components as the slurry flows through the system could be the limiting factor as to whether coal slurries are or are not utilized.

Using coal particles as a slurry is not new. Smith and Munsell (ref. 1) in 1879 patented the idea of mixing coal and petroleum as an improved fuel. More recently, Keller (ref. 2) in 1979 and Basta (ref. 3) in 1983 proposed the idea of using coal-water and coal-methanol slurries as a fuel. The idea is to mix finely comminuted coal with water or methanol in proportions of 50 to 75 wt % coal and 25 to 50 wt % water or methanol. Coal-methanol slurries have

an advantage over coal-water slurries in that they would burn more completely and reduce slagging.

Kesavan and Schrubens (refs. 4 and 5) have studied the effect of coal suspending additives on coal-methanol and coal-water slurries. They found the oils derived from coal help keep the coal in suspension and provides a flocking action that helps mitigate clogging. By a flocking action they mean that the particles do not tend to agglomerate while in solution and if sedimentation does occur, the deposits are loosely packed.

The purpose of this study was to study the tribological properties of coal-methanol slurries and to determine if a flocking additive (oil derived from coal) would improve the tribological properties of the slurries. For comparison, experiments were conducted on unlubricated steel and on methyl alcohol without coal additions. The experiments were conducted using a pin-on-disk tribometer.

## MATERIALS

The coal used in this study was a bituminous coal from Ohio. The particle size was 80 wt % of -200 mesh coal and 20 wt % of -180 + 200 mesh coal. Figure 1 gives a high magnification photomicrograph of the coal particles. The apparent density of the coal, as determined by liquid displacement of reagent grade kerosene in a pycnometer, was  $1.31 \text{ g/cm}^3$ . A proximate and an ultimate analysis of the coal is given in table I.

Commercial grade methyl alcohol (methanol) was used. The flocking additive was a SRC coal oil designated as V 1074. It was supplied by the Department of Energy, Pittsburgh, PA, and its characteristics are given in table II.

AISI M-50 tool steel or AISI 440C HT (high temperature) stainless steel pin-on-disk specimens were used. An elemental analysis of the steels is given in table III. Both steels are used as bearing steels.

### Pin-On-Disk Tribometer

A pin-on-disk tribometer was used in this study. The device has been described in detail in reference 6. A schematic of the apparatus is shown in figure 2. The friction specimens consisted of a rotating flat disk (6.3 cm diam) and a stationary, hemispherically tipped pin (0.467-cm radius). The pin slid on a 5.0-cm-diameter track on the disk at a rotational speed of 100 rpm which translates into a linear sliding speed of 0.26 m/sec.

## EXPERIMENTAL PROCEDURE

### Specimen Cleaning

The disks were first washed with ethyl alcohol to remove organic contaminants. They were then rubbed on a polishing wheel using a water paste of levigated alumina until a surface roughness of  $R_a = 0.070 \pm 0.020$  was obtained.

Cleaning with levigated alumina removes oxide films and helps smooth the surfaces. The disks were then scrubbed with a brush under running water to remove any adhering levigated alumina powder. To prevent oxidation, the disks were then quickly dried with clean, dry compressed air.

The pins were washed with ethyl alcohol and then scrubbed with a water paste of levigated alumina. They were then rinsed in distilled water and dried with clean, dry compressed air.

### Testing Conditions

The specimens were inserted into the tribometer, and the disk was set into rotation at 100 rpm (0.26 m/s). An eye dropper was used to manually apply the coal slurry to the rotating disk surface before applying the load. Once the disk surface was uniformly covered with liquid, a 9.8 N load was applied to the pin. Surface tension kept a uniform film of liquid on the disk, but some was depleted during the course of the tests due to centrifugal force. Liquid was added as needed to keep the disk surface fully flooded. Ambient room conditions were employed, a temperature of  $24 \pm 3$  °C and a relative humidity of  $60 \pm 10$  percent.

Each test was stopped at sliding intervals of approximately 75, 250, and 500 m of sliding so that pin wear volume could be measured and surface morphology could be studied by optical microscopy. In a few instances sliding was continued to 1000 m. After studying the surfaces, the specimens were remounted in the tribometer and the test procedure repeated. The pin was not removed from its holder, and locating marks ensured that it was returned to its original position.

After 500 m of sliding, some coal slurry tests were continued without adding any additional liquid (i.e., they were let run dry). Also, after 500 m of sliding, some coal slurry tests were continued by adding more liquid, but the coal slurry was rubbed with the experimenter's finger using a surgeon's glove. The procedure for conducting these tests was the same as the above stated method.

## RESULTS AND DISCUSSION

### Friction Coefficient

Friction coefficient as a function of sliding distance for M-50 bearing steel sliding on M-50 bearing steel is shown in figure 3. Four different conditions are shown: the unlubricated metal, the metal lubricated with methyl alcohol, the metal lubricated with a methyl alcohol-coal slurry, and the metal lubricated with a methyl alcohol-coal-flocking additive slurry. The bars in the figure represent the fluctuation of the friction coefficient on the strip chart recorder. In general, the less the fluctuation the more effective the lubricant was in providing wear protection.

The figure indicates that all three methyl alcohol slurries considerably reduced the friction when compared to the unlubricated metal. The mean friction coefficient of the methyl alcohol, the methyl alcohol-coal, and the methyl



alcohol-coal-flocking additive slurries were nearly the same. However, the coal powder additive did increase the fluctuation of the friction coefficient, indicating more of a stick-slip type of sliding action was taking place when the coal was present. The flocking additive tended to reduce the friction fluctuation caused by the coal.

Figure 4 gives friction coefficient as a function of sliding distance (for the four previously mentioned conditions) for tests conducted on 440C HT stainless steel sliding on itself. The same general friction characteristics were observed as were found for M-50 steel sliding on itself. No large differences in friction coefficients between those tests on 440C HT and M-50 steels were found.

Also shown on figure 4 is what happened to the friction coefficient for the methyl alcohol-coal-flocking additive slurry when additional liquid was not added to the disk and the film became dry. What happened was the friction coefficient became very stable and dropped to 0.10. A similar phenomenon occurred when this slurry was run dry on the M-50 steel disk. Possible reasons for this will be discussed later in the paper. When the coal slurry without the flocking additive was run dry, instead of dropping, the friction tended to increase very rapidly with sliding duration.

#### Pin Wear Rates

Figure 5 plots pin wear volume as a function of sliding distance for M-50 bearing steel sliding on M-50 bearing steel under the four test conditions previously mentioned. Wear to the disk is not shown since it was too small to measure. The pin wear volume for each condition tended to increase in a linear manner as a function of sliding distance. Wear rates were determined by linear regression analysis of the data and the values are given in table IV. As the table indicates, methyl alcohol without the coal additive gave the lowest wear rate, thus the coal particles did tend to increase the wear taking place. But as the figure and table show, the flocking additive tended to reduce the pin wear to almost one half the value obtained with the coal slurry alone.

Figure 6 shows pin wear volume as a function of sliding distance for 440C HT stainless steel sliding on 440C HT stainless steel. Similar results to the M-50 steel tests were obtained. The 440C HT stainless steel sliding on itself unlubricated gave considerably lower wear than did M-50 sliding on itself, but the methyl alcohol and coal slurry wear results were very similar to those obtained with M-50 steel (table IV).

Pin wear rates for the tests where the methyl alcohol-coal-flocking additive was run without any further liquid additions (run dry) and for the tests where the methyl alcohol-coal-flocking additive was rubbed with a surgical glove finger are also shown in table IV. Pin wear rates were found to be equivalent for the tests conducted on either 440C HT or M-50, but they were about 4 times less than those tests conducted with the wet coal slurries. In fact, the wear was about 1/2 that obtained for the methyl alcohol without the coal additives. Thus, even though the finger rubbed coal slurry with the flocking additive did not reduce the mean friction coefficient, a considerable reduction in wear did occur. More will be discussed about this in a later section. For the cases where the coal slurry without the flocking additive

was run dry or rubbed with the surgical glove finger, the pin wear rate steadily increased with sliding distance.

### Wear Surface Morphology

High magnification visual light photomicrographs of pin wear surfaces and disk wear surfaces that slid in the unlubricated condition for 200 m are given in figures 7 and 8, respectively. Both the M-50 and the 440C HT pin wear surface were covered with loose, fine, powdery metallic wear debris. There is very little difference in appearance between the two metals. The disk wear surfaces were covered with layers of worn material which had flowed together to form ridges. The M-50 steel had higher ridges than the 440C HT steel, which may have been due to the fact that the pin wear rate was greater.

Figures 9 and 10 give high magnification visual light photomicrographs of M-50 and 440C HT steel pin wear surfaces and disk wear tracks, respectively, after 200 m of sliding in methyl alcohol. The M-50 pin wear surface was covered with a continuous layer of small, flattened wear particles, while the 440C HT pin wear surface was covered with larger, less uniformly distributed, flattened wear particles. Flat wear particles were also observed on both the M-50 and 440C HT steel disks, and again they tended to be larger on the 440C HT steel surface. No loose powdery wear debris was found on pin wear surfaces and no thick wear surface layers were found on the disk wear surfaces, as were found in the unlubricated condition.

Figure 11 gives low magnification visual light photomicrographs of the 440C HT pin wear surfaces after 200 m of sliding in the methyl alcohol-coal slurry and in the methyl alcohol-coal-flocking additive slurry. The flocking additive tended to cause a very thick build-up of coal particles on the pin wear scar, while slurry with only coal produced a very thin layer of coal particles with small patchy areas of heavier concentration. Figure 12 shows high magnification photomicrographs of the surfaces in figure 11. For these high magnification photomicrographs, the heavy concentration of coal particles (which were on the pin wear scars) was rinsed off with methyl alcohol so the metal surface could be observed. The pin wear surfaces for the coal slurries with and without the flocking additive looked very similar, that is, they are worn very smooth and featureless.

A similar type of coal particle buildup (as described above) also occurred with the M-50 steel pin wear surfaces. But instead of the pin wear surfaces being worn very smooth and featureless as with 440C HT steel, the surfaces of M-50 steel pins were covered with cracks and pits. Cracking and pitting was observed for both the slurries with and without the flocking additive (fig. 13), but were not found for tests with only methyl alcohol. Apparently the localized stresses that the coal particles imparted while flowing through the M-50 pin contact area, induced fatigue-like cracks to form and spallation of the surface to occur. This points out the need to be very careful in choosing a steel for use in coal slurry applications.

No cracks or spalls were observed on either M-50 or 440C HT steel disk wear surfaces under any sliding condition. Figure 14 shows high magnification visual light photomicrographs of the M-50 steel disk wear track surfaces after 200 m of sliding in the methyl alcohol-coal slurries and in the methyl alcohol-

coal-flocking additive slurries. The disk wear track surfaces which slid in the coal slurries that contained the flocking additive showed more flat, layer-like deposits than those which slid in the coal only slurries. This indicated that the flocking additive tended to induce the deposition of surface layers which tended to provide a degree of boundary lubrication.

Figure 15 shows high magnification visual light photomicrographs of the 440C HT steel pin and disk surfaces after 400 m of sliding in the methyl alcohol-coal-flocking additive slurry which was allowed to dry out. That is, no further liquid slurry was added to the disk. A very thin, uniform film was observed on both the surfaces. It is believed that this film was formed from the flocking additive (coal oil) and provided the low friction and wear obtained. The film forming ability of the flocking additive in the dry state is a further indication that this additive is beneficial to the reduction of coal slurry wear. Surfaces similar to this were observed when M-50 steel surfaces were evaluated under the same conditions.

Figure 16(a) shows a low magnification overview of the pin wear scar area and figure 16(b) shows a high magnification view of the pin wear scar exit area for the test which was conducted in the methyl alcohol-coal-flocking additive slurry and which was kept wet but was rubbed constantly with the experimenter's finger as the disk rotated. As the photographic overview shows, the coal slurry has become "paste-like" or somewhat "grease-like" and this material completely surrounded the pin wear scar. The high magnification view shows a very thin liquid-like film on the scar which produced interference fringes. Also seen dispersed in the film are very fine coal particles. Apparently the action of rubbing the slurry induced the flocking additive to interact with the coal and metal surface to produce a material that had a very good film forming ability. Enough so, that the coal particles could pass through the contact area producing minimal wear. Again, showing the beneficial lubricating action of the flocking additive in reducing wear.

#### SUMMARY OF RESULTS

Pin-on-disk tribological studies on the effect of adding a flocking additive (coal oil) to methyl alcohol-coal power slurries indicate that:

1. The flocking additive did not markedly affect the friction coefficient of the coal slurries but it did lower wear about 50 percent.
2. The coal slurry (with and without the flocking additive) induced cracking and spalling to occur on the M-50 pin wear surface but not on the 440C HT steel surface, indicating the type of steel employed in utilizing these slurries could be very important.
3. The friction coefficient obtained with the unlubricated metal was greater than 0.75. The methyl alcohol alone or with the coal additions (with or without the flocking additive) provided a mean friction coefficient of about 0.18, indicating the methyl alcohol itself has lubricating ability and that the coal particles did not markedly affect this value.
4. The addition of fine coal powder to the methyl alcohol increased the pin wear up to four times as compared to the methyl alcohol alone.

5. Letting the coal slurry which contained the flocking additive run dry (i.e. not adding any further liquid to the disk surface) markedly reduced the friction coefficient and the pin wear rate as compared to the fully flooded condition, indicating the boundary film forming ability of the flocking additive. Reduced wear did not occur when the coal slurry without the flocking additive was run dry, in this case the friction and wear rate increased with sliding duration.

6. Rubbing the coal slurry (with the flocking additive) on the disk with a surgical glove covered finger did not reduce the friction but did reduce the wear when compared to the non-rubbed condition. This technique did not reduce the pin wear when the flocking additive was not present in the coal slurry.

#### REFERENCES

1. Smith, H.R. and Munsell, H.M., "Improvement in Liquid Fuels," U. S. Patent 219,181, (1879).
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3. Basta, N., "Coal-Water Slurries: A Step Away from Success," Chem. Eng., 90 [13] 14-16 (1983).
4. Kesavin, S.K. and Schrubens, D.L., "High Sulfur Coal Usage Through Coal-Oil Mixtures Using Suspending Media Derived from Coal," Presented at the First International Conference on High Sulfur Coal Utilization, Columbus, OH (1985).
5. Kesavan, S.K. and Schrubens, D.L., "Use of Coal Derivatives for the Stabilization of Coal-Water Slurries," Presented at the First International Conference on High Sulfur Coal Utilization, Columbus, OH (1985).
6. Fusaro, R.L., "How to Evaluate Solid Lubricant Films Using a Pin-on-Disk Tribometer," Lubr. Eng., 43, 330-338 (1987).

TABLE I. - PROXIMATE AND ULTIMATE  
ANALYSIS OF THE COAL SAMPLE  
[wt % Dry basis.]

	Coal
Proximate analysis	
Volatile matter	37.20
Ash	5.40
Fixed carbon	57.40
Ultimate analysis	
Carbon	83.50
Hydrogen	3.90
Nitrogen	1.20
Sulfur	3.80
Oxygen and errors	7.60

TABLE II. - COAL LIQUID CHARACTERISTICS

Specific gravity at 60 °F	0.927
ASTM distillation D-1160, °F	
5%	477
10%	488
30%	552
50%	600
70%	642
90%	754
95%	817
Pour point, °F	-36.4
Viscosity at 68 °F, mPa s	12.75
Carbon, wt %	88.3
Nitrogen	0.10
Hydrogen, wt %	11.2
Sulfur, wt %	0.07
Ash, wt %	0.02
Water, wt %	<0.03

TABLE III. - CHEMICAL COMPOSITION OF  
AISI M-50 AND 440C HT BEARING STEELS

Alloying element, wt %	Type of steel	
	M-50	440C HT
C	0.80	1.02
Mn	.30	.51
Si	.25	.21
S	.30	.007
P	.30	.15
Cr	4.00	14.15
V	1.00	.10
Ni	-----	.32
Mo	4.25	3.97
Fe	Balance	Balance

TABLE IV. - SUMMARY OF FRICTION COEFFICIENTS AND PIN WEAR RATES OBTAINED  
FOR METHYL ALCOHOL AND COAL SLURRIES

Sliding condition	Mean friction coefficient		Average pin wear rate (m <sup>3</sup> /m of sliding)	
	Type of steel			
	440C HT	M-50	440C HT	M-50
Unlubricated	0.95±0.10	0.85±0.10	(35±9)×10 <sup>-15</sup>	(130±30)×10 <sup>-15</sup>
Methyl alcohol lubricated	0.18±0.005	0.18±0.005	(8±2)×10 <sup>-15</sup>	(7±2)×10 <sup>-15</sup>
Methyl alcohol/ coal slurry	0.19±0.03	0.17±0.03	(23±4)×10 <sup>-15</sup>	(28±3)×10 <sup>-15</sup>
Methyl alcohol/coal/ flocking additive slurry	0.18±0.02	0.16±0.02	(15±2)×10 <sup>-15</sup>	(16±2)×10 <sup>-15</sup>
Methyl alcohol/coal/ flocking additive slurry (run dry)	0.10±0.02	0.10±0.02	(4±2)×10 <sup>-15</sup>	(4±2)×10 <sup>-15</sup>
Methyl alcohol/coal/ flocking additive slurry (rubbed with finger while sliding)	0.18±0.02	-----	(4±2)×10 <sup>-15</sup>	-----

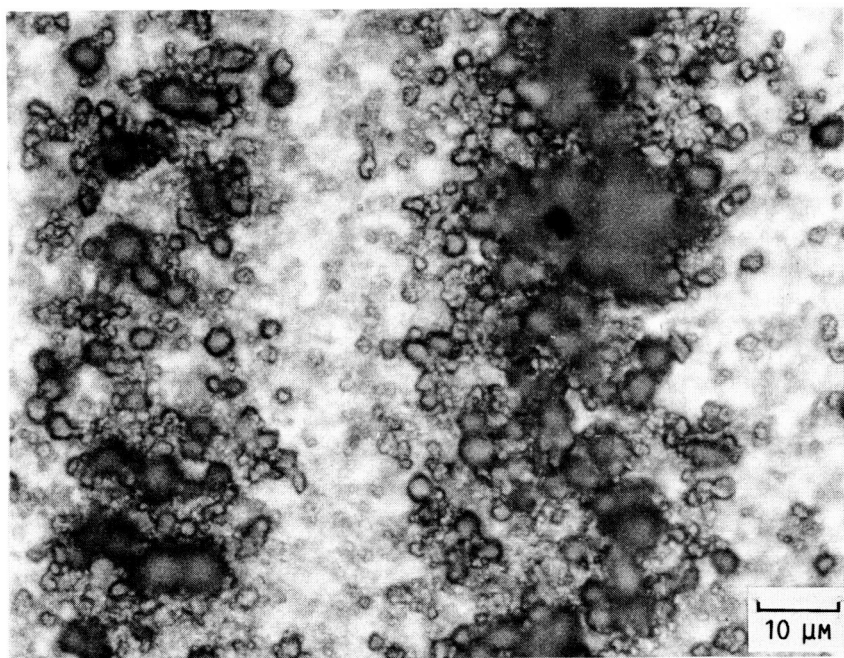


FIGURE 1. - HIGH MAGNIFICATION PHOTOMICROGRAPHS OF COAL PARTICLES.

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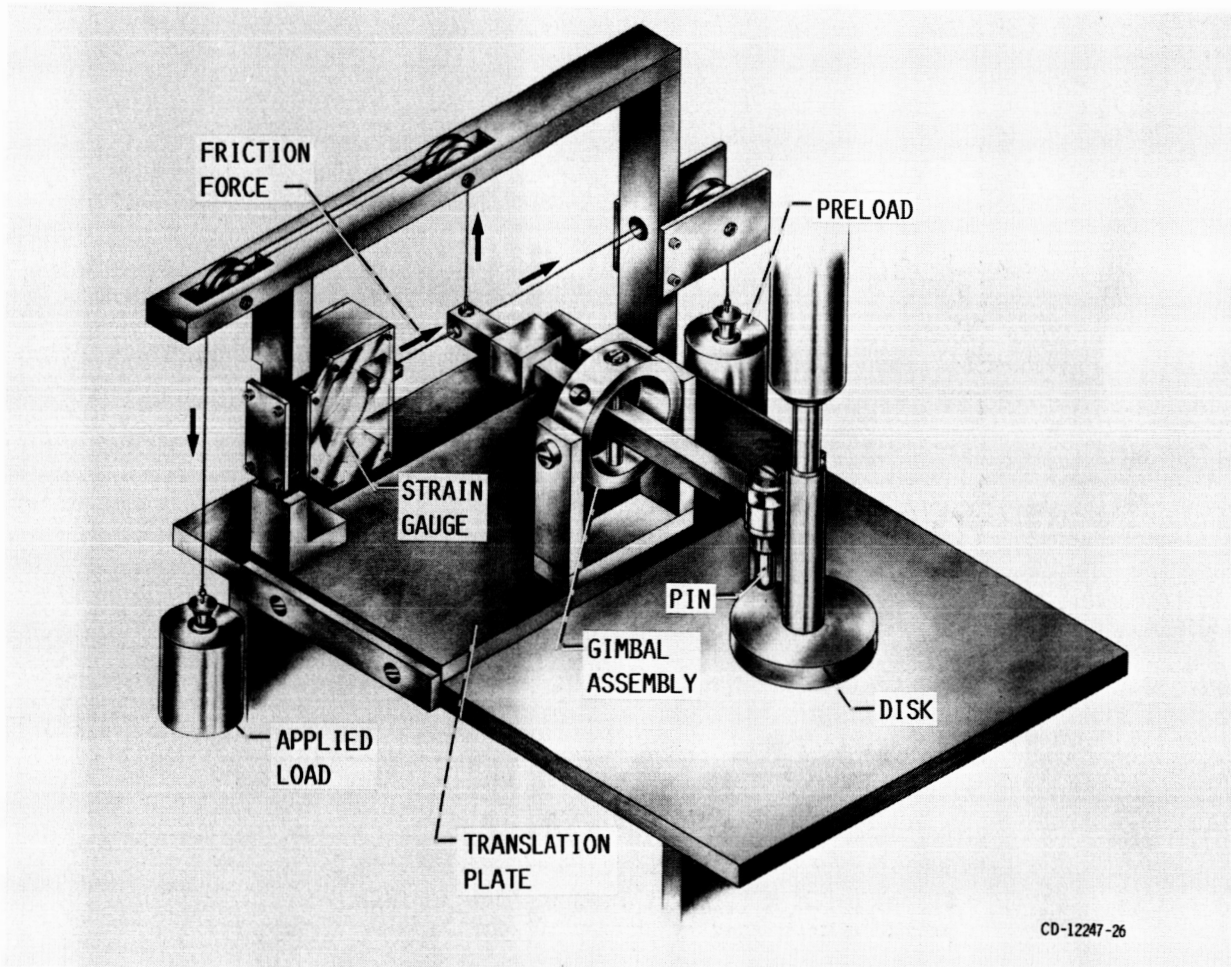


FIGURE 2. - SLOW SPEED PIN-ON-DISK TRIBOMETER.



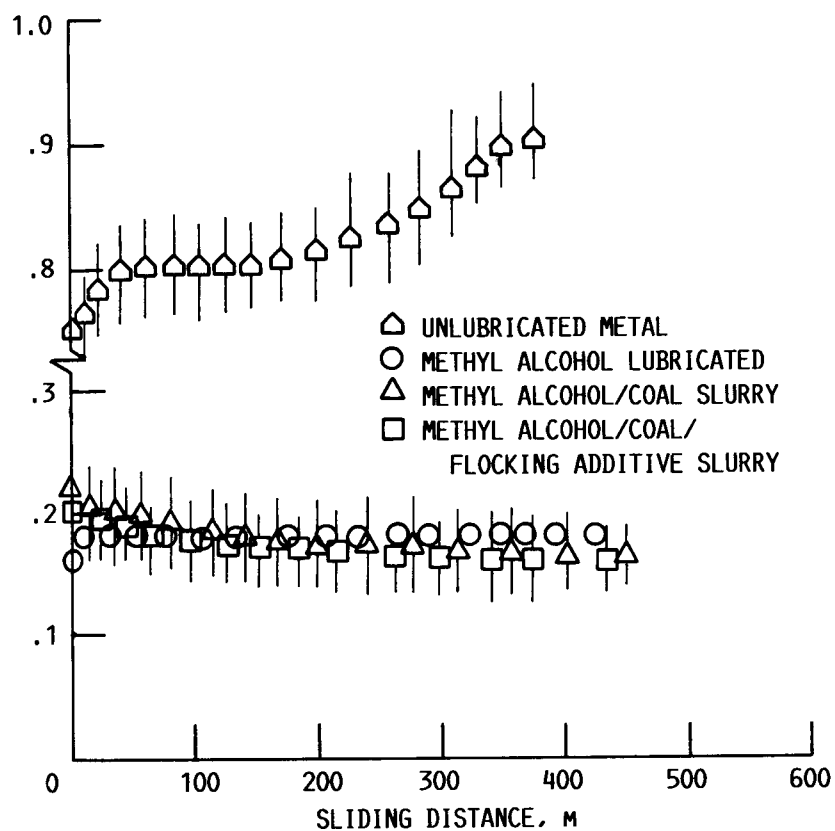


FIGURE 3. - FRICTION COEFFICIENT AS A FUNCTION OF SLIDING DISTANCE FOR M-50 STEEL PINS SLIDING AGAINST M-50 STEEL DISKS IN SOLUTIONS OF METHYL ALCOHOL, METHYL ALCOHOL/FINE COAL DUST SLURRIES, OR METHYL ALCOHOL/FINE COAL DUST AND A FLOCKING ADDITIVE.

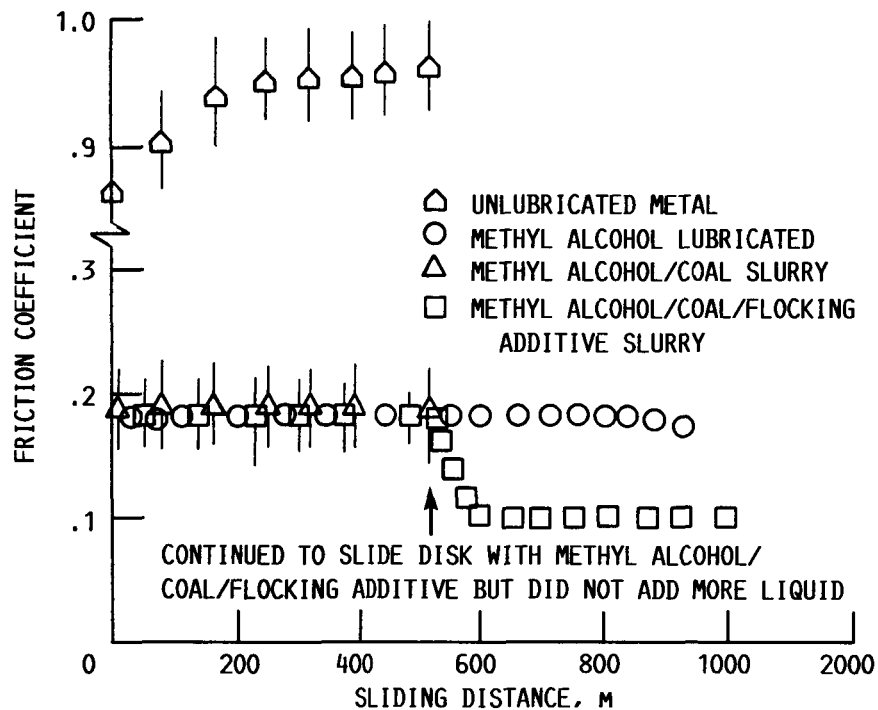


FIGURE 4. - FRICTION COEFFICIENT AS A FUNCTION OF SLIDING AGAINST 440C HT STAINLESS STEEL DISKS IN SOLUTIONS OF METHYL ALCOHOL, METHYL ALCOHOL/FINE COAL DUST SLURRIES, OR METHYL ALCOHOL/FINE COAL DUST AND A FLOCKING ADDITIVE.

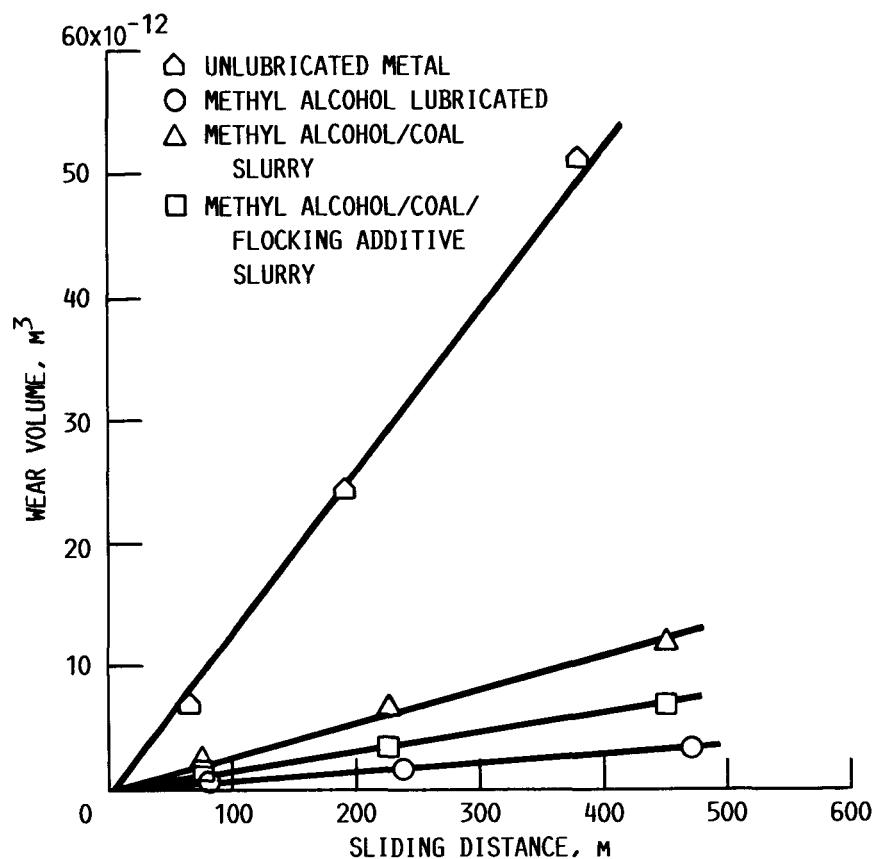


FIGURE 5. - PIN WEAR VOLUME AS A FUNCTION OF SLIDING DISTANCE FOR M-50 STEEL PINS SLIDING AGAINST M-50 STEEL DISKS IN SOLUTION OF METHYL ALCOHOL, METHYL ALCOHOL/FINE COAL DUST SLURRIES, OR METHYL ALCOHOL/FINE COAL DUST AND A FLOCKING ADDITIVE.

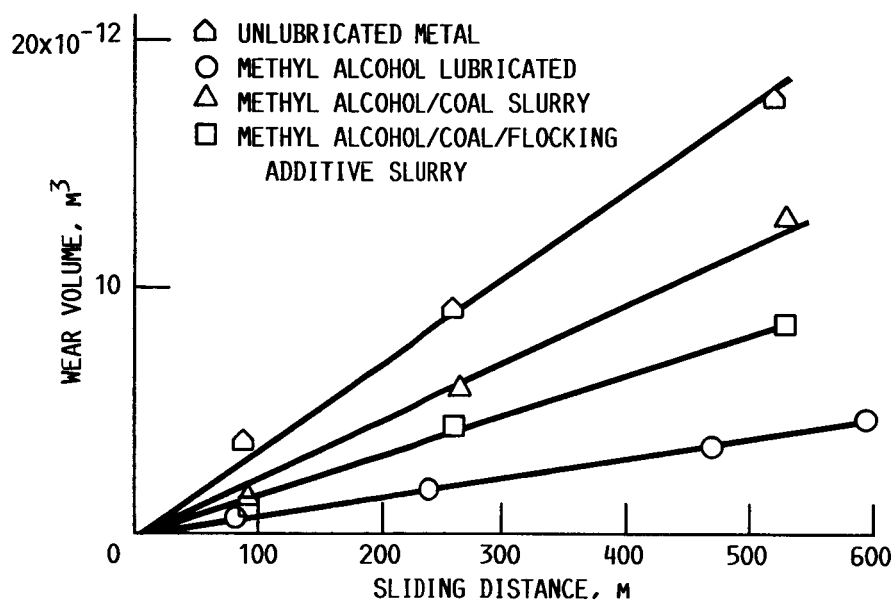
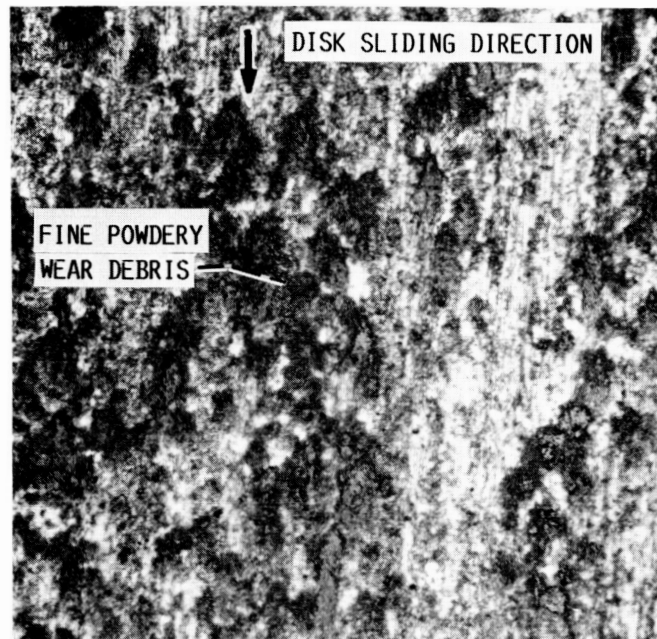
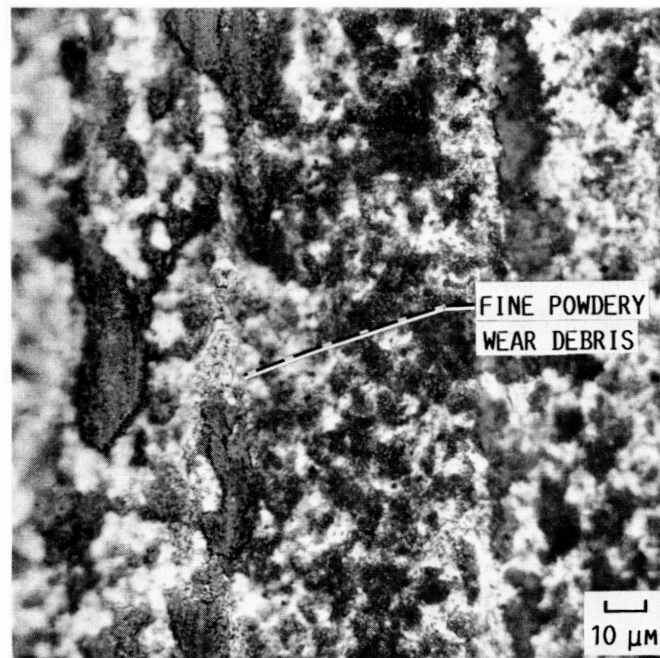


FIGURE 6. - PIN WEAR VOLUME AS A FUNCTION OF SLIDING DISTANCE FOR 440C HT STAINLESS STEEL PINS SLIDING ON 440C HT STAINLESS STEEL DISKS IN SOLUTIONS OF METHYL ALCOHOL, METHYL ALCOHOL/FINE COAL DUST SLURRIES, OR METHYL ALCOHOL/FINE COAL DUST AND A FLOCKING ADDITIVE.

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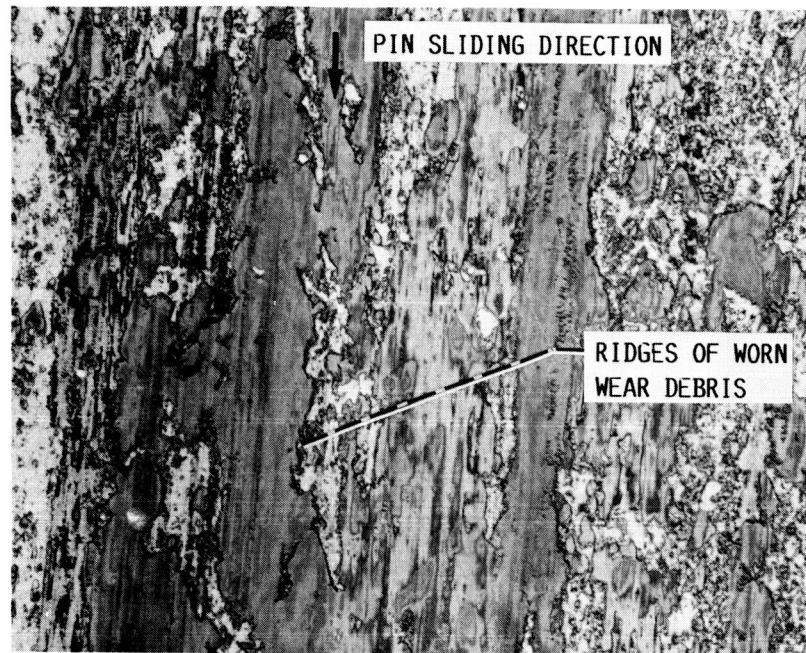
(A) M-50 STEEL.



(B) 440C HT STAINLESS STEEL.

FIGURE 7. - HIGH MAGNIFICATION PHOTOMICROGRAPHS  
OF PIN WEAR SURFACES WHICH SLID FOR 200 METERS  
DRY, WITHOUT METHYL ALCOHOL OR COAL ADDITIVES.

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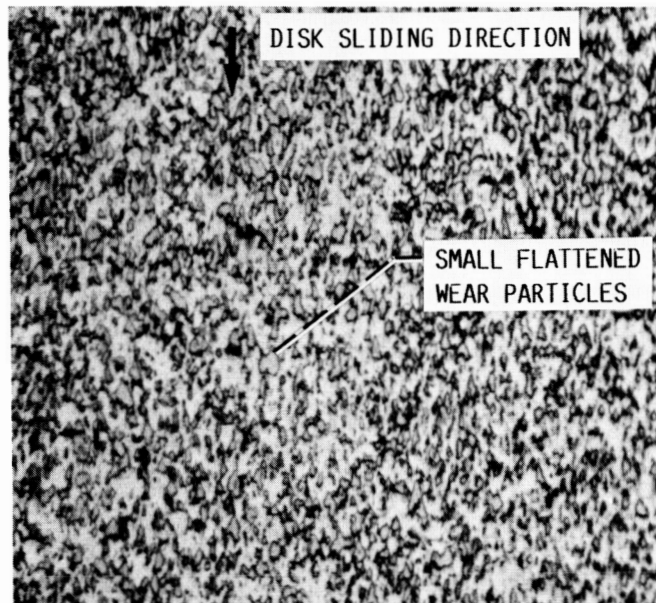
(A) M-50 STEEL.



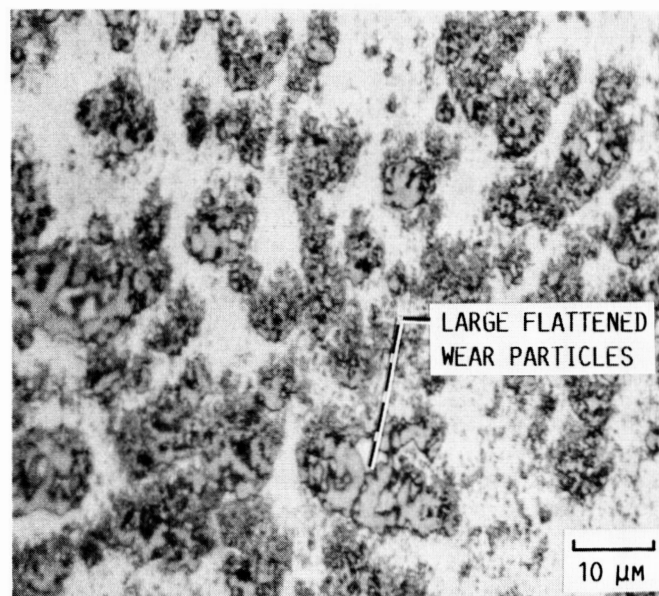
(B) 440C HT STAINLESS STEEL.

FIGURE 8. - HIGH MAGNIFICATION PHOTOMICROGRAPH OF DISK WEAR TRACK SURFACES WHICH SLID FOR 200 METERS DRY, WITHOUT METHYL ALCOHOL OR COAL PARTICLES.

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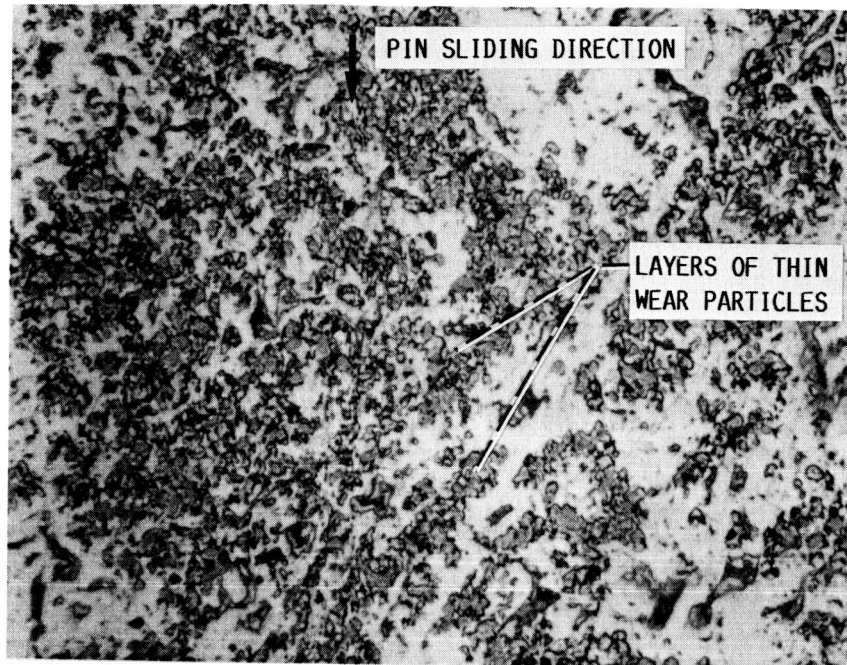


(A) M-50 STEEL.

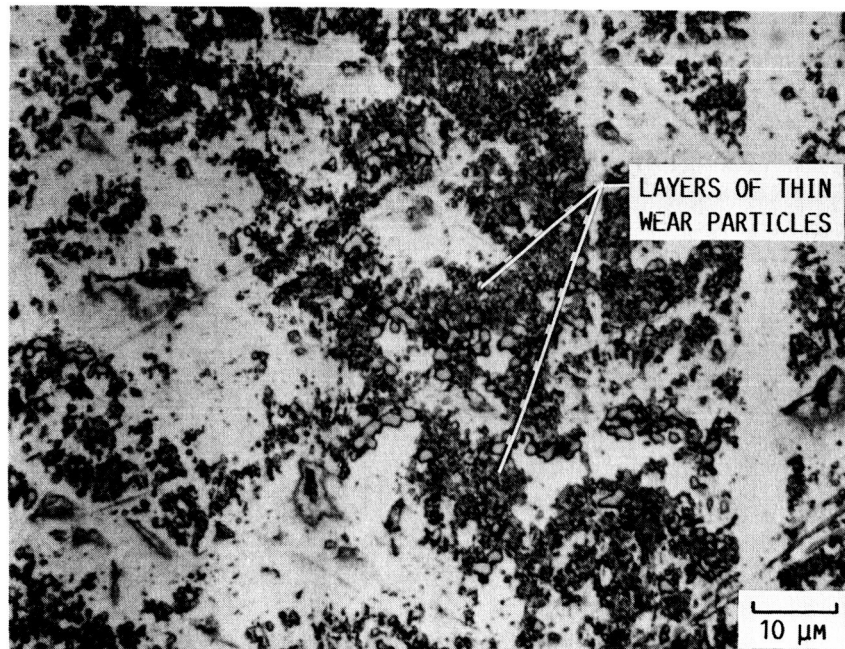


(B) 440C HT STAINLESS STEEL.

FIGURE 9. - HIGH MAGNIFICATION PHOTOMICROGRAPHS  
OF PIN WEAR OF PIN WEAR SURFACES AFTER 200  
METERS OF SLIDING LUBRICATED WITH METHYL  
ALCOHOL (NO COAL ADDITIVES).



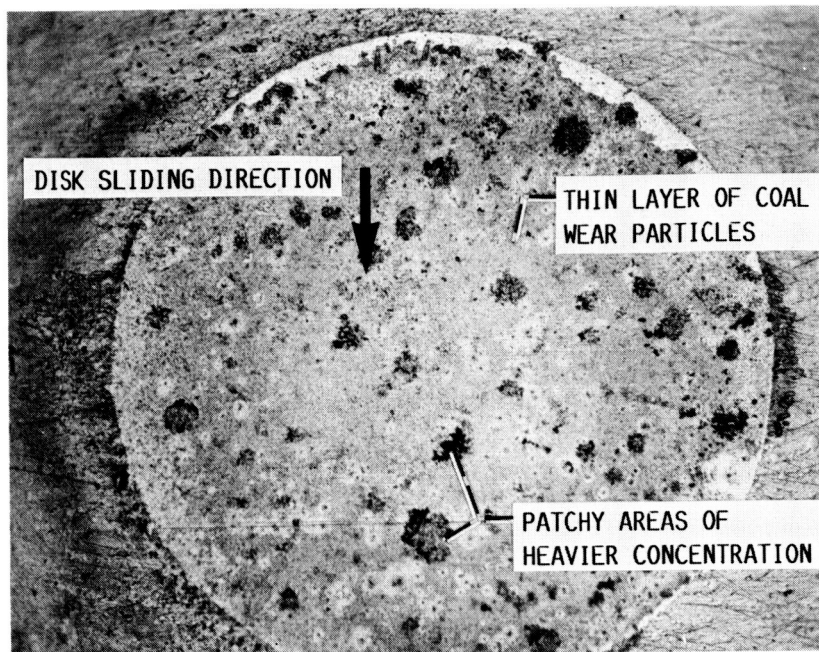
(A) M-50 STEEL.



(B) 440C HT STAINLESS STEEL.

FIGURE 10. - HIGH MAGNIFICATION PHOTOMICROGRAPHS OF DISK WEAR TRACKS AFTER 200 METERS OF SLIDING LUBRICATED WITH METHYL ALCOHOL (NO COAL ADDITIVES).





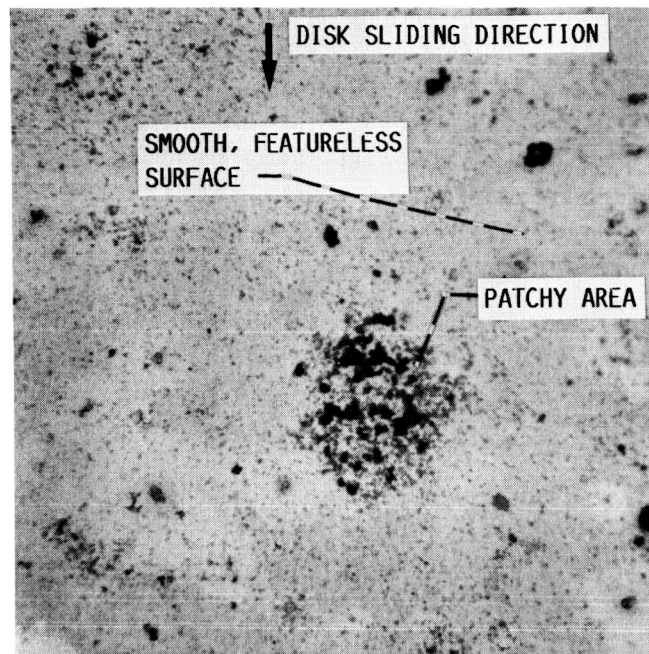
(A) METHYL ALCOHOL/COAL SLURRY.



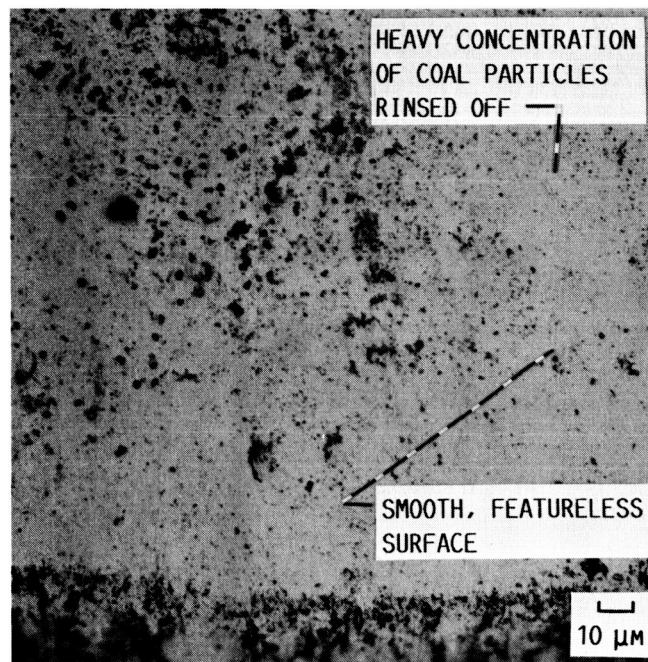
(B) METHYL ALCOHOL/COAL/FLOCKING ADDITIVE SLURRY.

FIGURE 11. - PHOTOMICROGRAPH OF 440C STAINLESS STEEL PIN WEAR SURFACES AFTER 200 METERS OF SLIDING IN A METHYL ALCOHOL/COAL COAL SLURRY OR A METHYL ALCOHOL/COAL/FLOCKING ADDITIVE SLURRY.

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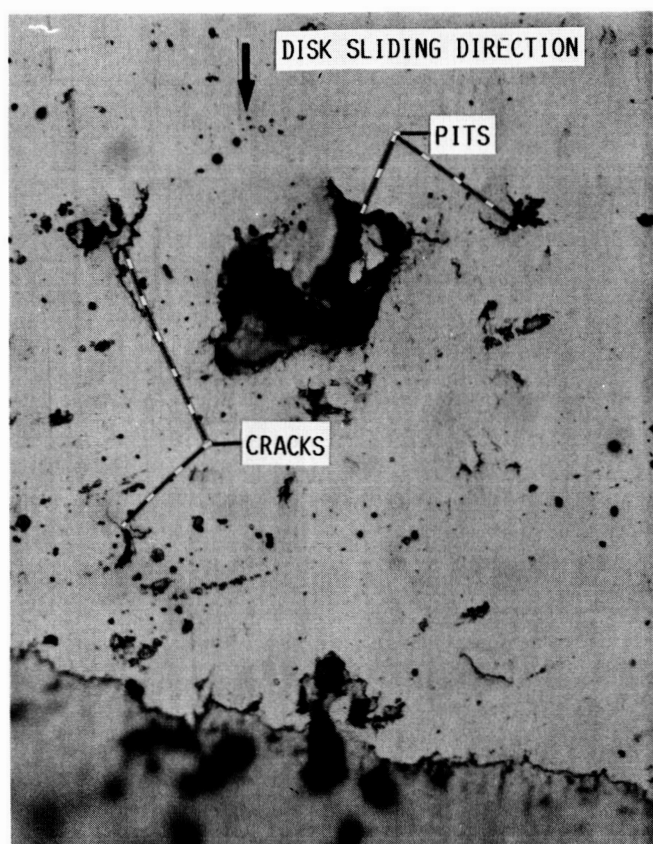


(A) METHYL ALCOHOL/COAL SLURRY.

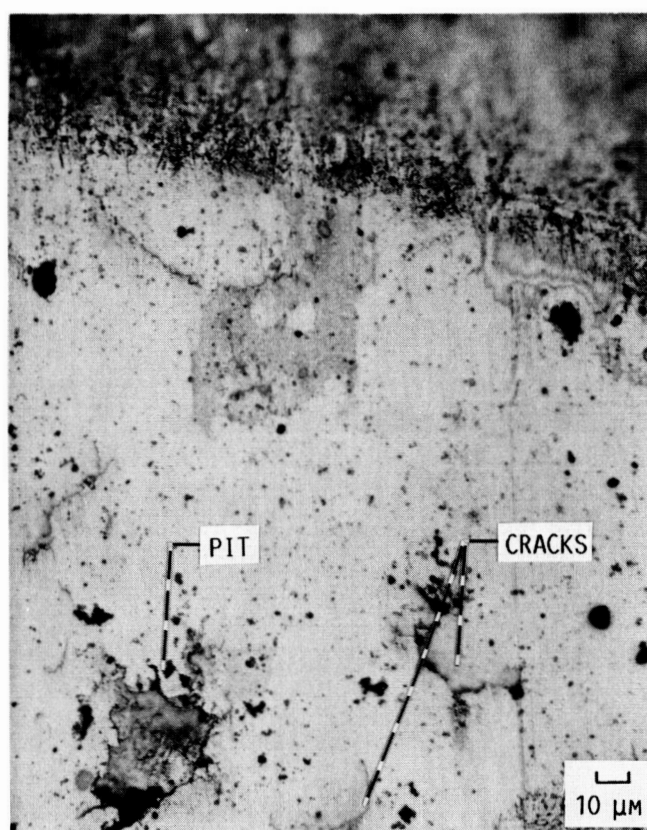


(B) METHYL ALCOHOL/COAL/FLOCKING ADDITIVE SLURRY.

FIGURE 12. - HIGH MAGNIFICATION PHOTOMICROGRAPHS OF 440C HT STAINLESS STEEL PIN WEAR SURFACES AFTER 200 METERS OF SLIDING IN A METHYL ALCOHOL/COAL SLURRY OR A METHYL ALCOHOL/COAL/FLOCKING ADDITIVE SLURRY.



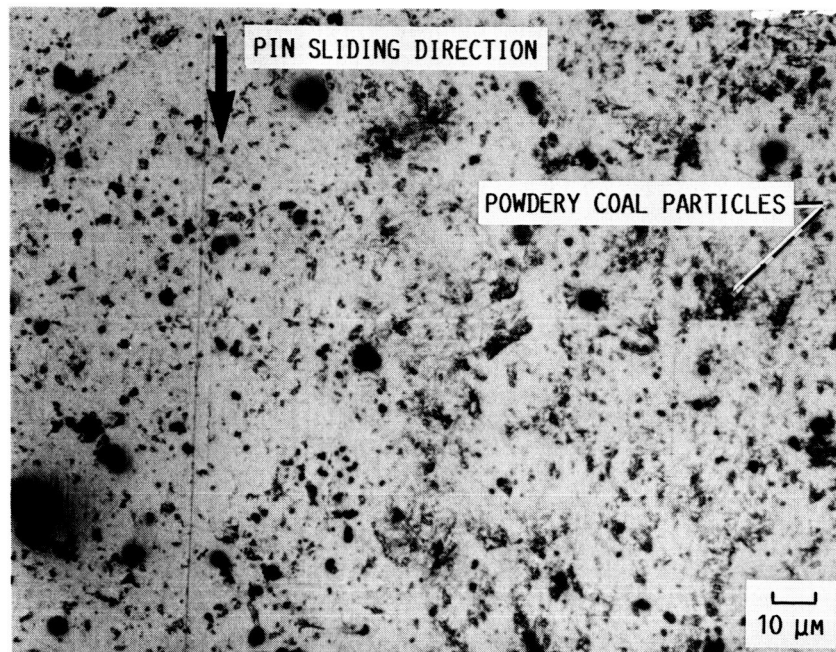
(A) METHYL ALCOHOL/COAL SLURRY.



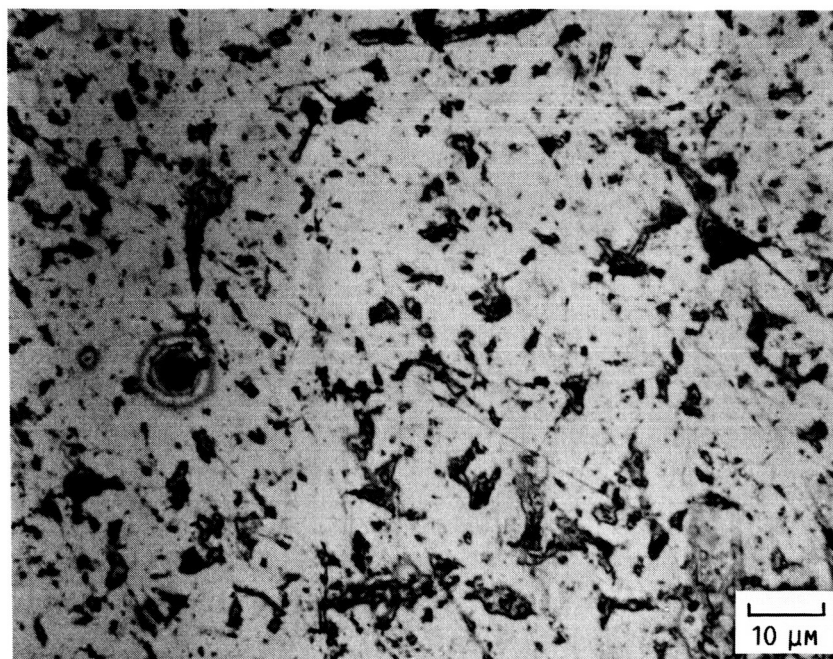
(B) MEHTYL ALCOHOL/COAL/FLOCKING ADDITIVE SLURRY.

FIGURE 13. - HIGH MAGNIFICATION PHOTOMICROGRAPHS OF M-50 STEEL SURFACES AFTER 200 METERS OF SLIDING IN METHYL ALCOHOL/COAL SLURRIES OR METHYL ALCOHOL/COAL/FLOCKING ADDITIVE SLURRIES.

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(A) METHYL ALCOHOL/COAL SLURRY.

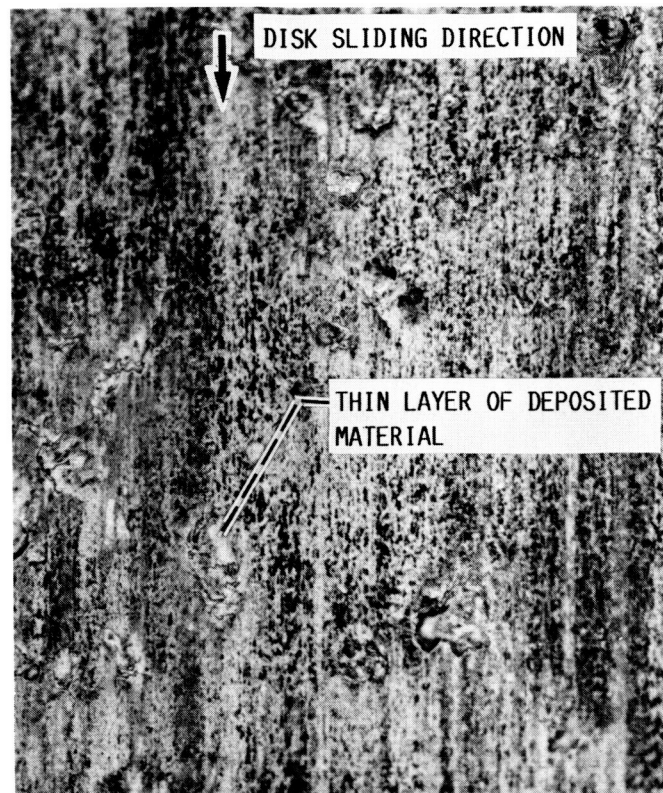


(B) METHYL ALCOHOL/COAL FLOCKING ADDITIVE SLURRY.

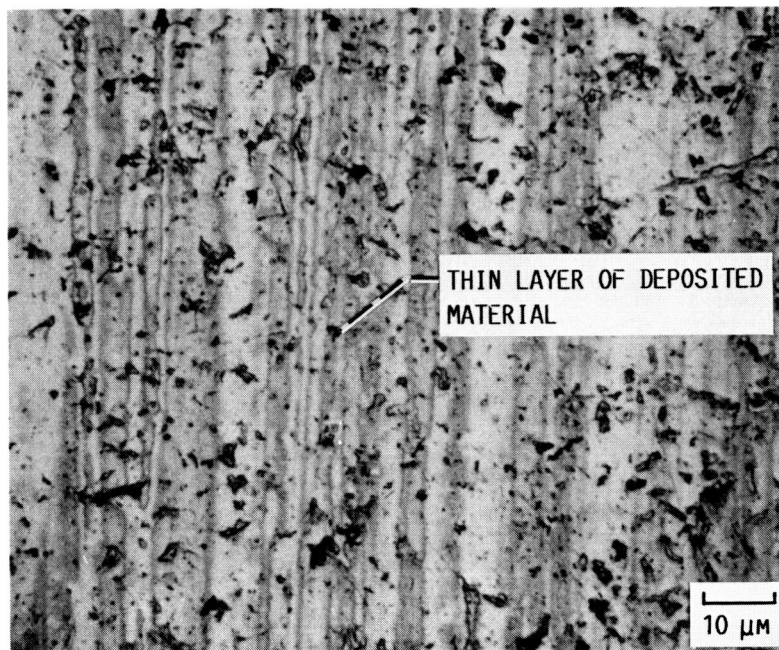
FIGURE 14. - HIGH MAGNIFICATION PHOTOMICROGRAPHS OF M-50 STEEL DISK WEAR TRACK SURFACES AFTER 200 METERS OF SLIDING IN A METHYL ALCOHOL/COAL SLURRY OR A METHYL ALCOHOL/COAL/FLOCKING ADDITIVE SLURRY.



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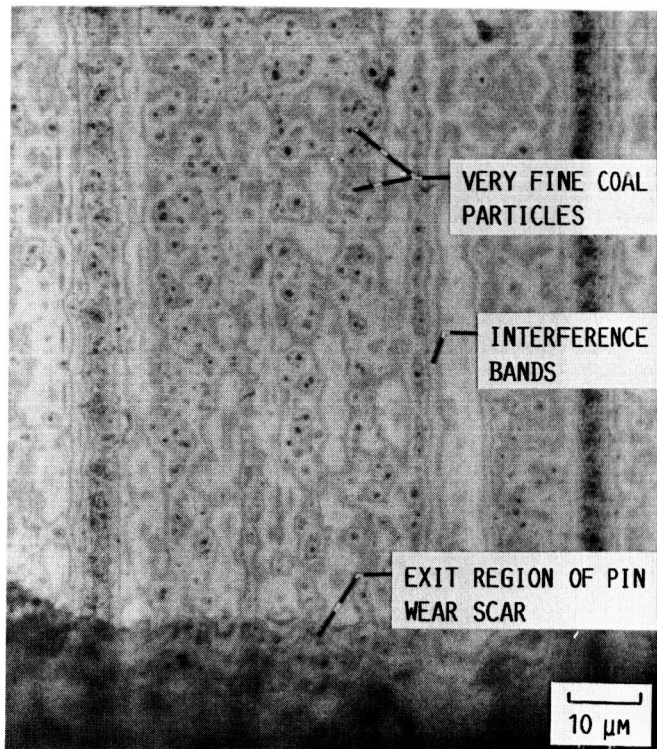
(A) PIN.



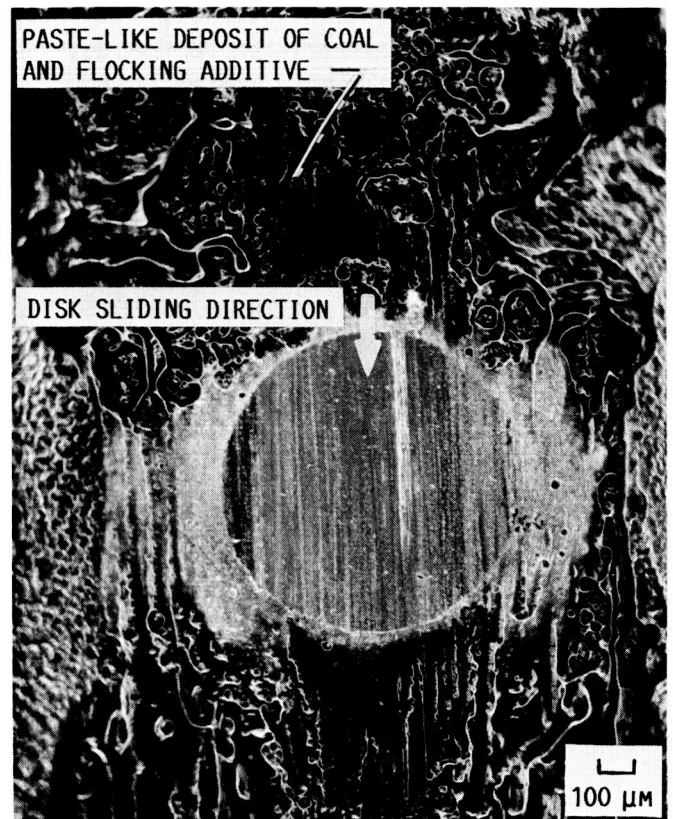
(B) DISK.

FIGURE 15. - HIGH MAGNIFICATION PHOTOMICROGRAPHS OF 440C HT PIN AND DISK WEAR SURFACES AFTER SLIDING FOR 400 METERS IN A METHYL ALCOHOL/COAL/FLOCKING ADDITIVE SLURRY WHICH WAS LET DRY OUT.

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(B) HIGH MAGNIFICATION VIEW OF PIN WEAR SCAR EXIT AREA.



(A) OVERVIEW OF PIN WEAR SCAR.

FIGURE 16. - PHOTOMICROGRAPHS OF M-50 PIN WEAR SCAR WHICH SLID IN A METHYL ALCOHOL/COAL/FLOCKING ADDITIVE SLURRY WHICH WAS FINGER RUBBED ON THE DISK AS THE TEST PROCEEDED.

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16. Abstract <b>A pin-on-disk tribometer was used to study the tribological properties of methyl alcohol-coal slurries. Friction coefficients, steel pin wear rates and wear surface morphological studies were conducted on AISI 440C HT and M-50 bearing steels which were slid dry and in solutions of methyl alcohol, methyl alcohol-fine coal particles, and methyl alcohol-fine coal particles-flocking additive. The flocking additive was an oil which was derived from coal and originally was intended to be added to the coal slurry to improve the sedimentation and rheology properties. The results of this study indicated that the addition of the flocking additive to the coal slurry markedly improved the tribological properties, especially wear. In addition, the type of steel was found to be very important in determining the type of wear that took place. Cracks and pits were found on the M-50 steel pin wear surfaces that slid in the coal slurries while 440C HT steel pins showed none.</b>					
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